

ASCE STANDARD

American Society of Civil Engineers

Design and Construction of Frost-Protected Shallow Foundations

American Society of Civil Engineers

Design and Construction of Frost-Protected Shallow Foundations

This document uses both Système International (SI) and customary units.



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ABSTRACT

This standard addresses the design and construction of frost-protected shallow foundations in areas subject to seasonal ground freezing. Foundation insulation requirements to protect heated and unheated buildings from frost heave are presented in easy-to-follow steps with reference to design tables, climate maps, and other necessary data to furnish a complete frost-protection design. The advantages of this technology include improved construction efficiency over conventional practices, increased energy efficiency, minimized site disturbance, and enhanced frost protection. A commentary is included to provide background information and important technical insights.

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- ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures
- Building Code Requirements for Masonry Structures (ACI 530-99/ASCE 5-99/TMS 402-99) and Specifications for Masonry Structures (ACI 530.1-99/ASCE 6-99/TMS 602-99)
- ASCE 7-98 Minimum Design Loads for Buildings and Other Structures
- ANSI/ASCE 8-90 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members
- ANSI/ASCE 9-91 listed with ASCE 3-91
- ASCE 10-97 Design of Latticed Steel Transmission Structures
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- ASCE 14-93 Standard Guidelines for Operation and Maintenance of Urban Subsurface Drainage
- ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
- ASCE 16-95 Standard for Load and Resistance Factor Design (LRFD) of Engineered Wood Construction
- ASCE 17-96 Air-Supported Structures
- ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing
- ASCE 19-96 Structural Applications of Steel Cables for Buildings
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- ASCE 26-97 Standard Practice for Design of Buried Precast Concrete Box Sections
- ASCE 27-00 Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction
- ASCE 28-00 Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction
- EWRI/ASCE 33-01 Comprehensive Transboundary International Water Quality Management Agreement
- EWRI/ASCE 34-01 Standard Guidelines for Artificial Recharge of Ground Water

FOREWORD

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This Standard was prepared through a consensus standards process by balloting in compliance with procedures of the ASCE Structural Engineering Institute. Those individuals who serve on the Frost-Protected Shallow Foundations Standard Committee are:

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Design and Construction of Frost-Protected Shallow Foundations

1. SCOPE AND LIMITATIONS

This Standard addresses the design and construction of frost-protected shallow foundations to prevent frost damage in cold climates with seasonal ground freezing. For the purpose of this Standard, a frost-protected shallow foundation is a foundation that does not extend below the design frost depth, but is protected against effects of frost. This Standard applies to buildings on potentially frost-susceptible ground with slab-on-ground or suspended floor foundations. This Standard does not apply to buildings on permafrost, to areas with mean annual outdoor air temperatures less than 32°F (0°C), or to areas with design air-freezing indexes greater than 4,500°F-days (60,000°C-hr).

This Standard addresses heated, unheated, and semi-heated structures, as classified by the minimum average monthly indoor temperature expected during the building's intended useful life. For the purpose of using this Standard, the building shall be classified in accordance with Table 1.

This Standard does not preclude the judgment and practice of those competent in foundation design and the prevention of frost damage, nor does it preclude compliance with other design considerations or local building code requirements. Structural requirements, other than frost protection, shall be in accordance with the building code or accepted design practices and are not included in this Standard.

TABLE 1. Classification of Building Based on Indoor Air Temperature

Minimum Average Monthly Indoor Temperature, T	Thermal Classification
$T \geq 63^\circ\text{F}$ (17°C)	Heated
41°F (5°C) < T < 63°F (17°C)	Semi-heated
$T \leq 41^\circ\text{F}$ (5°C)	Unheated

2. REFERENCES

American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). *Handbook of Fundamentals*, Atlanta, GA (1997).

American Society for Testing and Materials (ASTM). ASTM C578-95. *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*, West Conshohocken, PA (1995).

American Society for Testing and Materials. ASTM D422-63 (90). *Test Method for Particle-Size Analysis of Soils*, West Conshohocken, PA (1990).

American Society for Testing and Materials. ASTM D2487-93. *Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)*, West Conshohocken, PA (1993).

3. SYMBOLS, UNITS, AND DEFINITIONS

3.1 SYMBOLS AND UNITS

The symbols and units used throughout this Standard are found in Table 2. Conversion factors for units are found in Table 3. English units accompanied by soft conversions to SI units (shown in parentheses) are used throughout the Standard.

3.2 DEFINITIONS

Approved: Accepted by the building official of the jurisdiction as the result of investigations, analysis, tests, or any combination of these evaluation approaches or by reason of accepted principles or local experience.

Air-Freezing Index (AFI): Determined from cumulative degree days above and below 32°F (0°C), recorded for an annual cycle. The AFI for a given winter is the largest difference between the maximum freezing degree day cumulative total reached at the start of the winter season and the minimum total reached during the winter.

Cold-Bridges: Discontinuities in insulation that create thermally conductive pathways and increase the potential for frost damage.

Design Air-Freezing Index (F_{100}): The 100-year mean return period AFI used in this Standard for protection of building foundations against frost damage.

Design Frost Depth: The minimum depth at which the soil temperature remains above freezing for an extreme winter event, based on analysis, local regulations, or experience.

Effective Thermal Resistivity (r_{eff}): An adjusted thermal resistivity to account for long-term use in a moist, below-ground condition. Commonly referred to in this Standard as an effective R per inch.

Effective Thermal Resistance (R_{eff}): An adjusted R-value to account for long-term use in a moist, below-ground condition.

TABLE 2. Symbols and Units

Symbol	Description	SI Units	English Units
D_h	Width of horizontal wing insulation along walls	m	ft or in
D_{hc}	Width of horizontal wing insulation at corners	m	ft or in
D_g	Width of ground insulation beyond the perimeter of an unheated building	m	ft or in
F_{100}	100-year mean return period AFI	$^{\circ}\text{C}\cdot\text{hr}$	$^{\circ}\text{F}\cdot\text{days}$
h	Floor height above finished grade	m	ft or in
h_f, h_{fc}	Foundation depth along walls or at corners	m	ft or in
h_v	Depth of vertical wall insulation into ground (minimum footing depth)	m	ft or in
L_1, L_2, L_3	Length of unheated portion of otherwise heated building	m	ft or in
L_c	Length (along a wall) of corner insulation	m	ft or in
MAT	Mean annual air temperature	$^{\circ}\text{C}$	$^{\circ}\text{F}$
R_f	R-value of floor/slab construction or assembly	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_v	Required R-value of vertical wall insulation	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_h	Required R-value of horizontal wing insulation	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_{hc}	Required R-value of horizontal wing insulation at corner	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_g	Required R-value of ground insulation for unheated buildings	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
R_{eff}	Effective R-value (thermal resistance) of an insulation material in service conditions	$\text{m}^2\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$
r_{eff}	Effective resistivity (R_{eff} per inch) of an insulation material in service conditions	$\text{m}\cdot^{\circ}\text{K}/\text{W}$	$\text{hr}\cdot\text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}\cdot\text{in}$

Frost Heave: The expansion of soil due primarily to the growth of ice lenses in the soil. Frozen soil beneath a foundation can cause upward movement of the foundation and/or settlement from thaw weakening of the soil.

Frost-Protected Shallow Foundation (FPSF): Foundations protected from frost heave by insulating in accordance with these provisions. Insulation is provided to retard frost penetration below the foundation and to retard heat flow from beneath the foundation, allowing shallower footing depths to be possible with no added risk of frost damage. Use of non-frost-susceptible soils is also included in certain applications.

Ground Insulation: Insulation extending horizontally underneath a foundation to create an insulated pad for the building.

Mean Return Period Air-Freezing Index: A probability estimate of the average number of years between which a number of total winter season freezing degree days will be equaled or exceeded; a 100-year mean return period occurs in 1% of the years (1/100), has a 1% annual probability of exceedance, or is exceeded once every 100 years on average.

Mean Annual Air Temperature (MAT): The average of all daily average outdoor air temperatures (minimum plus maximum daily temperature divided by two) in one or more years.

Mean Return Period (Mean Recurrence Interval): A probability estimate of the average number of years between which an event of a given magnitude

will be equaled or exceeded ($1/p$, where p is the probability of an event happening over a specified period).

Non-Frost-Susceptible Soil: A soil that does not display significant detrimental ice segregation (i.e., ice lens development) during freezing. Generally, granular soils with less than 6% by mass passing a #200 sieve (0.074 mm) have low frost susceptibility, whereas silts and clays or sands and gravels (i.e., granular soils) with high fines content generally have medium to high frost susceptibility.

TABLE 3. Unit Conversions

Length	1 m = 100 cm = 3.28 ft = 39.4 in
Mass	1 kg = 2.2 lbm (0.0683 slugs)
Weight	1 N = 0.225 lbf
Area	1 m ² = 10,000 cm ² = 10.8 ft ² = 1550 in ²
Volume	1 m ³ = 1 × 10 ⁶ cm ³ = 35.3 ft ³ = 6.1 × 10 ⁴ in ³
Density	1 kg/m ³ = 0.0624 lbf/ft ³ (pcf)
Pressure	1 kPa = 0.145 lbf/in ² (psi) = 20.8 lbf/ft ² (psf)
Temperature	$^{\circ}\text{F} = 1.8 (^{\circ}\text{C} + 32)$
Freezing index	1 $^{\circ}\text{C}\cdot\text{hr} = 0.075^{\circ}\text{F}\cdot\text{days}$
Thermal properties:	
• resistance	1 m ² · $^{\circ}\text{K}/\text{W} = 5.68 \text{ hr} \cdot \text{ft}^2\cdot^{\circ}\text{F}/\text{Btu}$ {R-value}
• resistivity	1 m· $^{\circ}\text{K}/\text{W} = 0.144 \text{ hr} \cdot \text{ft}^2\cdot^{\circ}\text{F}/(\text{Btu} \cdot \text{in})$ {R/in}

Permafrost: Soil that, in its natural state, remains frozen throughout the year. Generally occurs in regions where the mean annual soil surface temperature is below freezing.

R-Value (Thermal Resistance): A measure of the ability to retard heat flow for a given thickness ($\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu}$) [$\text{m}^2 \cdot \text{K}/\text{W}$]. It is calculated by dividing the material's thickness by its thermal conductivity. The thermal resistance of material assembled in layers is calculated by summing the thermal resistances of the individual components.

Suspended Floor: A floor not directly supported by the earth, such as a floor over a basement or crawlspace.

Thermal Resistivity: The insulative capability of a material to retard heat flow for a unit thickness of homogeneous material over a unit area, commonly given as R per inch.

Vertical Insulation: Insulation placed vertically against the exterior perimeter surface of the foundation.

Wing (Horizontal) Insulation: Insulation placed in a horizontal position or sloped downward and away from exterior walls of a foundation (abuts the vertical foundation wall insulation).

4. DESIGN PRINCIPLES

4.1 GENERAL

In regions of seasonal ground freezing, shallow foundations not extending below the design frost depth shall be protected against frost heave by one or more of the following methods:

1. use of non-frost-susceptible layers of undisturbed ground or fill materials (Section 4.2);
2. insulation of foundations to mitigate frost penetration and effects of frost heave (Section 4.3); or
3. approved design and details supported by engineering analysis.

4.1.1 Bearing Capacity

The allowable bearing capacity of the undisturbed soil, fill materials, or insulating materials supporting the foundation shall be equal to or greater than the structural loads imposed by the building in accordance with the local building code or engineering analysis. The foundation depth, as measured from finished grade to bottom of footing, shall be the greater of that required by this Standard or that required for adequate bearing capacity on soil or fill. The foundation depth,

as measured from finished grade to bottom of footing, shall not be less than 12 inches (0.3 m).

4.1.2 Drainage

The site shall be graded to drain surface water away from foundation walls, in accordance with local building code provisions or approved practice. In soils other than GW, GP, SW, SP, GM, and SM (Unified Soil Classification System, ASTM D2487), a layer of screened and washed gravel or crushed stone shall be placed beneath the horizontal insulation and drained to daylight, or an approved foundation drainage system shall be provided.

4.1.3 Compaction

Fill materials shall be placed and compacted in accordance with an approved design or approved practice. An approved design shall be required for fill materials that support foundation loads and are more than 12 inches (0.3 m) thick or vary in thickness by more than 6 inches (0.15 m).

4.1.4 Insulation Protection

Vertical insulation placed externally on foundation walls or along edges of slab-on-ground floors shall have an opaque and weather-resistant protective covering to mitigate degradation of thermal performance from ultraviolet radiation, physical damage, or other sources of deterioration. Protective coverings or coatings shall be compatible with the insulation material and extend a minimum of 6 inches (0.15 m) below finished grade. Polystyrene insulation shall not be exposed to petroleum-based products. Horizontal insulation placed less than 12 inches (0.3 m) below the ground surface, or any portion extending outward more than 24 inches (0.6 m) from the foundation edge, shall be protected against damage by concrete or asphalt pavement on the ground surface directly above the insulation by cementitious board or plywood rated for below-ground use, or by other approved materials placed directly on the top surface of the insulation.

4.1.5 Termite Protection

Buildings with underground foam insulation in geographic areas subject to termite infestation with structural members constructed of materials susceptible to termite damage shall comply with local building code requirements for termites and shall be protected against termite infestation. Methods of protection shall include chemical soil treatment, physical barriers (such as termite shields), or any combination of these methods.

4.2 FOUNDATIONS ON NON-FROST-SUSCEPTIBLE GROUND OR FILL MATERIAL

Foundations placed on a layer of well-drained, undisturbed ground or fill material that is not susceptible to frost shall have the thickness of such a layer included in meeting the design frost depth defined in Section 3.2. Undisturbed granular soils or fill material with less than 6% of mass passing a #200 (0.074 mm) mesh sieve in accordance with ASTM D422 and other approved non-frost-susceptible materials shall be considered non-frost-susceptible. Classification of frost susceptibility of soil shall be determined by a soils or geotechnical engineer, unless otherwise approved.

4.3 FOUNDATIONS WITH INSULATION TO PREVENT GROUND FREEZING

Frost-protected shallow foundations (FPSF) shall be designed in accordance with the following sections of this Standard using the design data from Appendix A:

- Section 5 Simplified FPSF Design Method for Heated Buildings with Slab-on-Ground Foundations
- Section 6 FPSF Design Method for Heated Buildings
- Section 7 FPSF Design Method for Unheated Buildings
- Section 8 Special Design Conditions for FPSF

Buildings with foundations designed in accordance with Section 5 or 6 that are not completed and not heated before the time of first ground freezing shall have additional temporary ground protection or temporary heating of internal space in accordance with Table 1, or the foundation shall be designed in accordance with provisions for unheated buildings (Section 7).

5. SIMPLIFIED FPSF DESIGN METHOD FOR HEATED BUILDINGS WITH SLAB-ON-GROUND FOUNDATIONS

Designs based on the following simplified procedure shall be permitted to be used to specify insulation for slab-on-ground foundations of heated buildings, in lieu of the detailed design in Section 6. Design procedures of Section 6 shall be used when buildings include suspended floors. Unheated areas, such as attached garages, shall be designed in accordance with Section 7, except when designed in accordance with Section 4.2 or when the foundation of the unheated area extends below the design frost depth. Cold-bridges shall be prevented (see Section 8.4).

Step 1: Select the Site's Design Air-Freezing Index, F_{100} *2500 and 45degrees*

The 100-year mean return period AFI, F_{100} , shall be selected from Figure A1 or Table A3 of Appendix A.

Step 2: Determine Insulation R-Value, Dimensions, and Footing Depth

Using F_{100} from Step 1, select vertical and horizontal insulation R-values, horizontal insulation dimensions, and minimum footing depth from Table 4. Verti-

TABLE 4. Minimum Insulation Requirements for Frost-Protected Shallow Foundations of Heated Buildings¹

Air-Freezing Index, F_{100} (° F-days)	Vertical Insulation R-value, R_v	Horizontal Insulation R-value, R_h (hr · ft ² · ° F/Btu)		Horizontal Insulation Dimensions per Figure 1 (in)			Minimum Footing Depth (in)
		Along Walls	At Corners	D_h	D_{hc}	L_c	
500 or less	0	NR	NR	NR	NR	NR	12
1,500	4.5	NR	NR	NR	NR	NR	12
2,000	5.6	NR	NR	NR	NR	NR	14
2,500	6.7	1.7	4.9	12	24	40	16
3,000	7.8	6.5	8.6	12	24	40	16
3,500	9.0	8.0	11.2	24	30	60	16
4,000	10.1	10.5	13.1	24	36	60	16
4,500	12.0	12.0	15.0	36	48	80	16

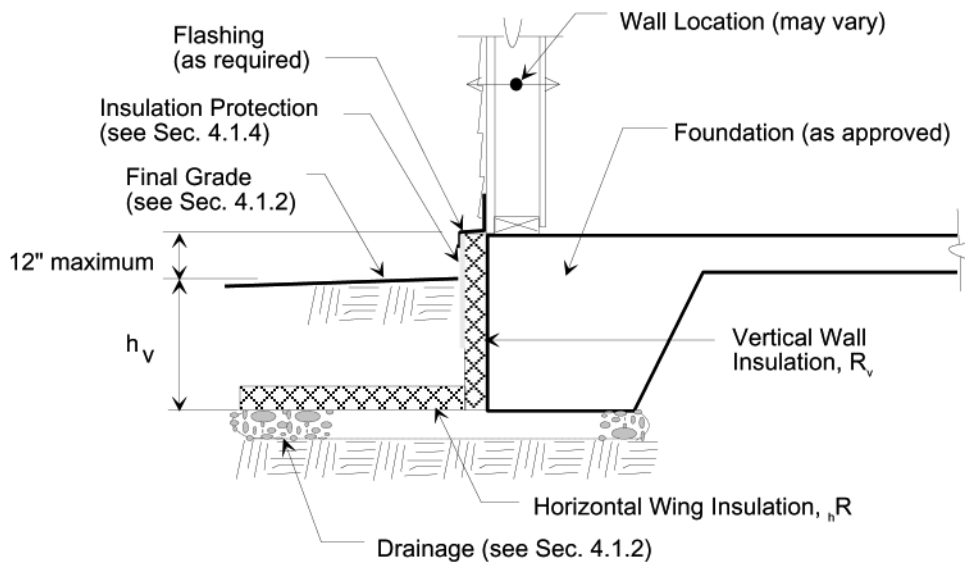
¹ Insulation requirements are for protection against frost damage in heated buildings. Interpolation between values is permissible. For interpolation purposes, NR = 0 (NR = not required).

cal and horizontal insulation shall be located on the foundation in accordance with Figure 1. The insulation shall be placed to prevent cold-bridging between the foundation wall or other thermally conductive materials of the building foundation and the adjacent soil or outside air (see Section 8.4). Horizontal insulation shall be bedded firmly on a smooth ground surface or, where required by Section 4.1.2, a drained granular base. When foundation depths, h_v , greater than 12 inches (0.3 m) are required by Table 4, the increase in depth may be satisfied by substituting non-frost-susceptible fill materials, as defined in Section 4.2. Insulation placed below

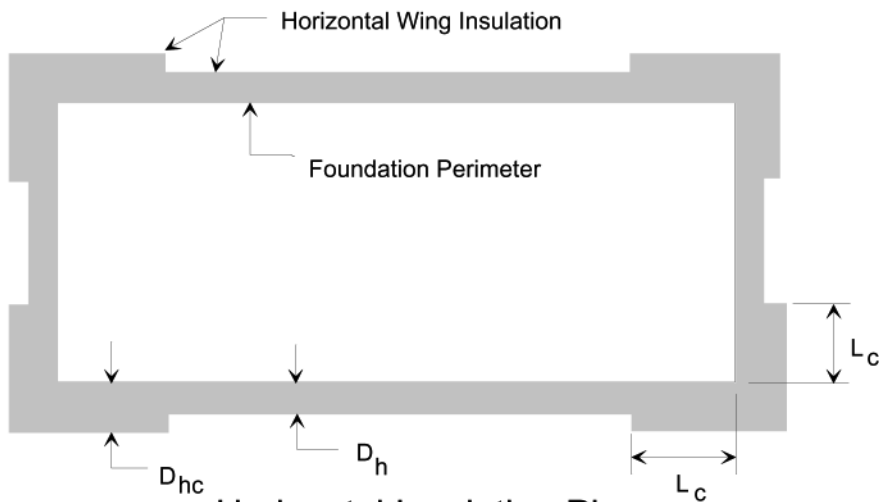
the floor slab shall not exceed a nominal R-value of 10 ($\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu}$) [$1.76 \text{ m}^2 \cdot ^\circ\text{K}/\text{W}$].

Step 3: Select Insulation Types, Calculate Thicknesses, and Provide Protection

An approved insulation material type shall be selected in accordance with Section A.2.2 of Appendix A. Insulation thicknesses shall be determined by dividing the required vertical and horizontal insulation R-values (thermal resistance), R_v and R_h , from Step 2 by the selected insulation material's effective resistivity, r_{eff} , in accordance with Table A1 of Appendix A. The insulation material thickness of individual panels shall



Insulation Detail



Horizontal Insulation Plan

FIGURE 1. FPSF Design Parameters for Heated Buildings Using the Simplified Design Procedure

DESIGN AND CONSTRUCTION OF FROST-PROTECTED SHALLOW FOUNDATIONS

not be less than the minimum insulation thickness in Table A1 of Appendix A. Insulation materials shall be protected in accordance with Section 4.1.4.

See Figure A1 to determine design AFI (F_{100}).

6. FPSF DESIGN METHOD FOR HEATED BUILDINGS

6.1 SLAB-ON-GROUND FOUNDATIONS

The design procedure in this section shall be used to specify foundation insulation for slab-on-ground

foundations of heated buildings in accordance with Figure 2 and the design data in Appendix A. For semi-heated buildings, the additional requirements of Section 8.3 shall apply. Cold-bridges shall not be permitted (see Section 8.4).

Step 1: Select the Site's Design Air Freezing Index, F_{100}

The 100-year mean return period AFI, F_{100} , shall be selected from Figure A1 or Table A3 of Appendix A.

2500 and 45degrees

Step 2: Determine the R-Value for the Floor Slab, R_f

Determine the thermal resistance of the floor system, R_f , by multiplying the nominal dry resistivity in

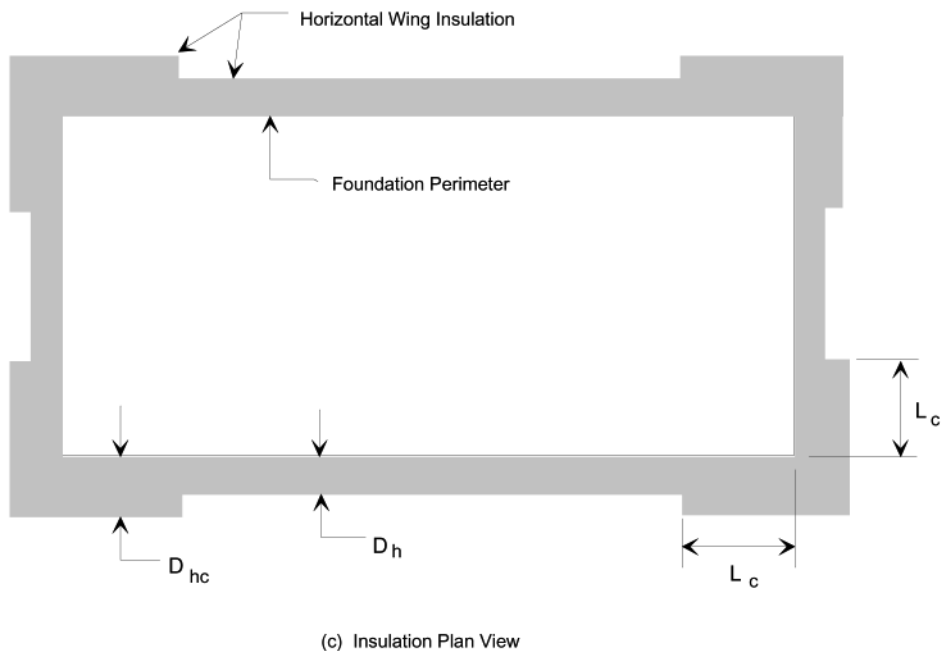
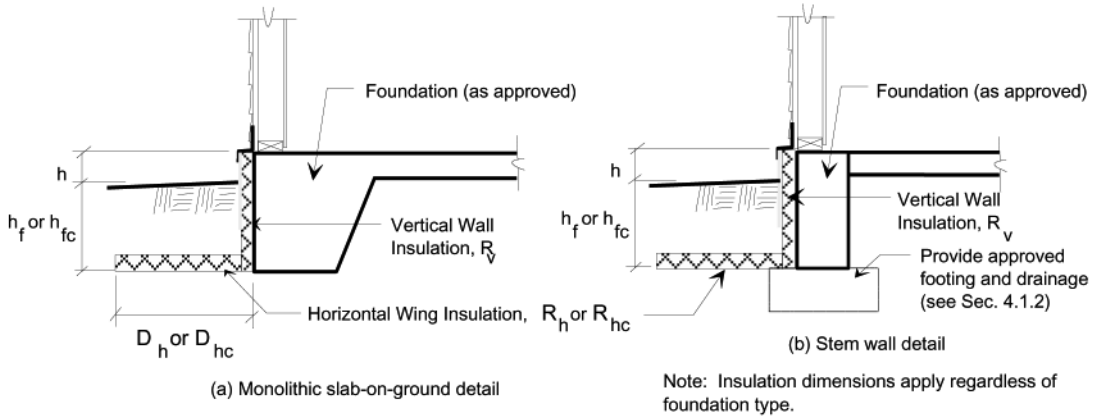


FIGURE 2. Slab-on-Ground Foundation for Heated Buildings

Table A2 of each material in the cross-section, including any floor coverings, by its thickness. Sum the thermal resistances of the materials to obtain total R_f . If no portion of the outer 3 feet (0.9 m) of the slab exceeds $R_f = 28$, proceed to Step 3. Treat small portions of the slab in the outer 3 feet (0.9 m) that exceed $R_f = 28$ as small unheated areas in otherwise heated buildings in accordance with Section 8.1. Where the R_f value of the entire slab exceeds 28, follow the design procedure for unheated buildings.

Step 3: Select the Required R-Value for Vertical Wall Insulation, R_v

The minimum required thermal resistance of vertical wall insulation, R_v , shall be selected from Table A4, given a site-specific value for h as shown in Figure 2, F_{100} from Step 1, and R_f from Step 2.

Step 4: Select Vertical Insulation Type, Calculate Thickness, and Provide Protection

An approved insulation material type shall be selected in accordance with Section A.2.2 of Appendix A. Based on the required R_v value from Step 3, calculate the required thickness of vertical wall insulation by dividing R_v by the insulation material's effective resistivity, r_{eff} , for vertical applications provided in Table A1 of Appendix A. The insulation material thickness of individual panels shall not be less than the minimum insulation thickness in Table A1 of Appendix A. The insulation shall extend from a depth of h_f or h_{fc} to the exterior, **above-grade wall without exposing the foundation wall or other thermally conductive materials as shown in Figure 2. Vertical wall insulation shall be protected in accordance with Section 4.1.4.**

Step 5: Select Foundation Depth or Horizontal Wing Insulation for Walls

Horizontal wing insulation is placed as shown in Figure 2. For climates where F_{100} is less than **2,250°F-days** (30,000°C-hr), wing insulation along the walls is not required, and the designer shall proceed to Step 7. If horizontal wing insulation is not desired in more severe climates, select the minimum foundation depth, h_f , from Table A5 in Appendix A. If a foundation depth of 16 inches (0.41 m) is desired in severe climates ($F_{100} > 2,250^\circ\text{F-days}$ [30,000°C-hr]), select the minimum width of wing insulation, D_h , and the required minimum thermal resistance of insulation, R_h , from Table A6 in Appendix A.

Step 6: Select Horizontal Insulation Type, Calculate Thickness, and Provide Protection

Select an approved insulation material type in accordance with Section A.2.2 of Appendix A. Determine the required insulation thickness by dividing R_h by the insulation material's effective resistivity, r_{eff} , provided in Table A1 in Appendix A. The thickness of

individual panels shall not be less than the minimum insulation thickness in Table A1 of Appendix A. Wing insulation shall meet flush with the vertical wall insulation in accordance with Figure 2. Insulation materials shall be protected in accordance with Section 4.1.4.

Step 7: Select Foundation Depth or Horizontal Wing Insulation at Corners

Where horizontal wing insulation is not desired, select the minimum foundation depth at corners, h_{fc} , from Table A5 of Appendix A. For a uniform foundation depth, $h_f = h_{fc}$, use Table A5 with $R = 5.7$ wing insulation applied to the corner regions. The minimum thickness of the wing insulation at corners shall be determined by dividing R by the insulation material's effective resistivity, r_{eff} , provided in Table A1. If a foundation depth of 16 inches (0.4 m) is desired in severe climates ($F_{100} > 2,250^\circ\text{F-days}$), select the minimum width the wing insulation shall extend from the foundation wall, D_{hc} , and the minimum required thermal resistance of the insulation, R_{hc} , from Table A7.

Calculate the required minimum thickness of the corner wing insulation by dividing R_{hc} by the insulation material's effective resistivity, r_{eff} , for horizontal applications provided in Table A1. Determine the minimum distance the corner insulation shall extend from the corners, L_c , from Table A7. Protect horizontal insulation at corners in accordance with Section 4.1.4.

Step 8: Check Compressive Load on Horizontal Insulation

If horizontal wing insulation extends under the footing, compressive loads from the foundation shall not exceed allowable insulation bearing capacity provided in Table A1 of Appendix A.

6.2 UNVENTED CRAWLSPACE FOUNDATIONS

The design procedure in this section shall be used to specify foundation insulation for unvented crawlspace foundations of heated buildings in accordance with Figure 3 and the design data in Appendix A.

Step 1: Review Important Design Considerations

Crawl spaces that are unvented during the heating season shall be permitted to have the foundation insulation design as required for heated or semi-heated buildings (Table 1), provided the following conditions are met:

- The floor assembly nominal R-value, R_f , does not exceed $28 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu}$ ($4.9 \text{ m}^2 \cdot ^\circ\text{K}/\text{W}$) in accordance with Table A4 of Appendix A, or the crawlspace is conditioned as a heated or semi-heated space (Table 1).

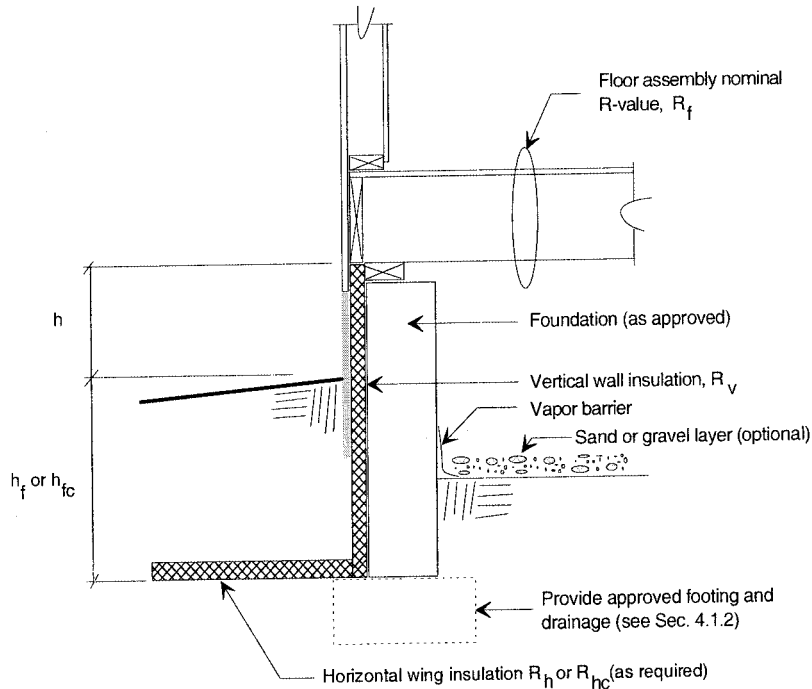


FIGURE 3. Insulation Placement for Crawlspace Foundation for Heated or Semi-Heated Buildings

- The height from the exterior ground elevation to the underside of the floor joist, h , is not greater than 24 inches (0.6 m) in all areas.

The provisions of Section 7.2 shall be used for vented or unheated crawlspaces.

Step 2: Follow the Detailed Method for Heated Buildings

Follow the eight design steps of Section 6.1 for slab-on-ground construction to determine insulation requirements for crawlspace foundations. For semi-heated buildings, the additional requirements of Section 8.3 shall apply. Cold-bridges shall not be permitted (see Section 8.4).

6.3 WALK-OUT BASEMENTS

The design procedure in this section shall be used to specify foundation insulation for heated, walk-out basements in accordance with Figure 4 and design data in Appendix A.

Step 1: Review Important Design Considerations

Basements shall be designed as heated or semi-heated buildings, provided the following conditions are met:

- The basement is sufficiently conditioned to be considered a heated or semi-heated space (Table 1).

- The vertical insulation extends from a depth of h_f or h_{fc} or frost depth, if higher, to the top of the basement wall without interruption, and without cold-bridging (see Section 8.4).

Step 2: Follow the Detailed Method for Heated Buildings

Follow the eight design steps of Section 6.1 for slab-on-ground construction to determine insulation requirements for a basement foundation. When required, horizontal wing insulation shall be applied only to the shallow, walk-out portions of the basement as shown in Figure 4. Vertical insulation on the basement wall shall be applied as shown in Figure 4. For semi-heated basements, additional requirements of Section 8.3 shall apply. Cold-bridges shall not be permitted (see Section 8.4).

7. FPSF DESIGN METHOD FOR UNHEATED BUILDINGS

7.1 SLAB-ON-GROUND FOUNDATION

The design procedure in this section shall be used to specify foundation insulation for unheated buildings with slab-on-ground foundations in accordance with Figure 5 and the design data in Appendix A.

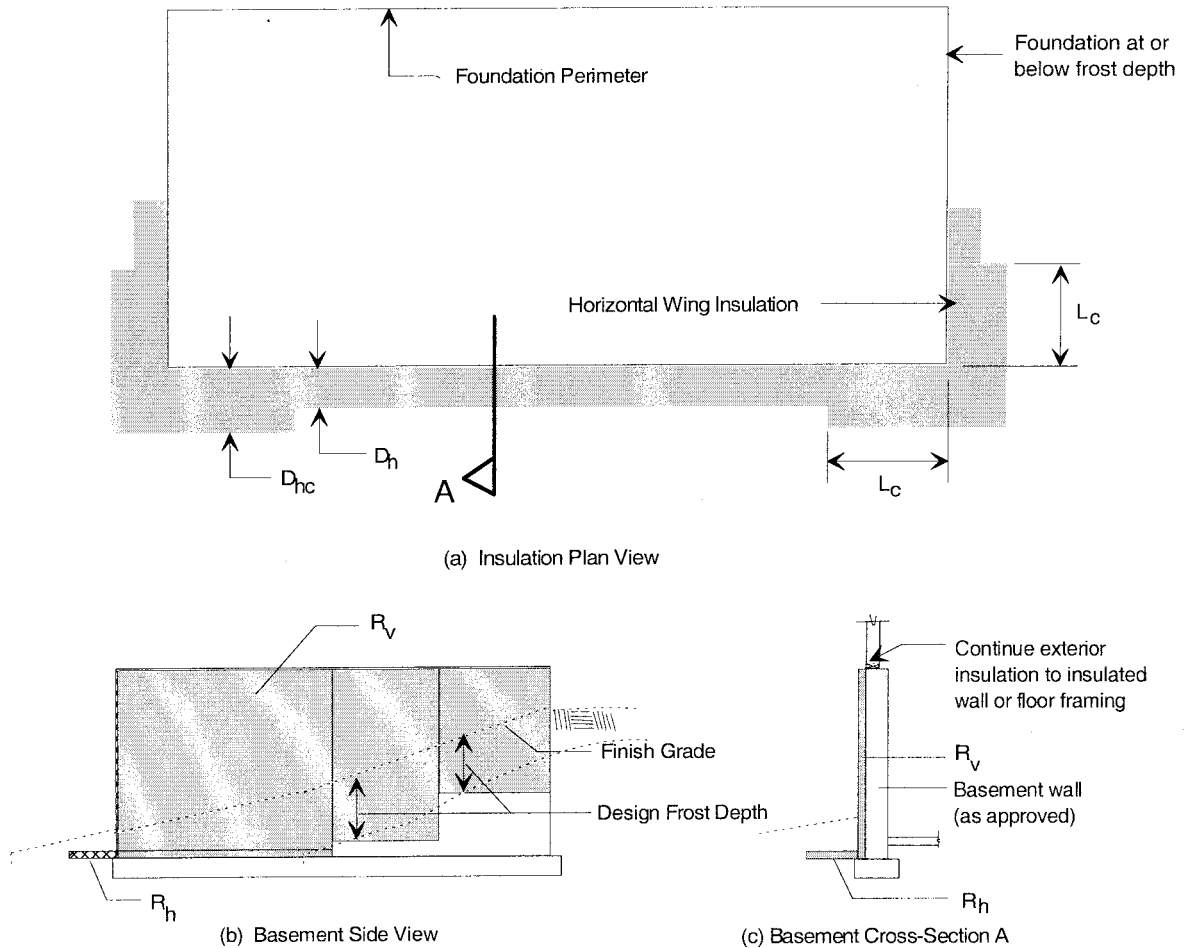


FIGURE 4. Walk-Out Basement Details for Heated or Semi-Heated Buildings

Step 1: Select the Design Air-Freezing Index, F_{100} , and Mean Annual Temperature

The 100-year mean return period AFI, F_{100} , shall be selected from Figure A1 or Table A3. Select the mean annual exterior temperature, MAT, from Figure A2 or Table A3.

Step 2: Determine Placement of Ground Insulation

A continuous ground insulation layer over a minimum 6-inch (0.15-m) non-frost-susceptible soil layer shall be placed below the entire foundation of unheated buildings. The non-frost-susceptible soil layer shall be increased to 12 inches (0.3 m) if placed above the insulation layer. The ground insulation layer and the non-frost-susceptible layer shall be additive to the minimum footing depth of 12 inches (0.3 m), as shown in Figure 5. The ground insulation shall extend outside the foundation a minimum width, D_g , as determined from Table A8 and shown in Figure 5. In unheated buildings, D_g is the same at both corner and wall locations. Outside

the foundation perimeter, the insulation shall have a minimum of 10 inches of soil cover. D_g may be reduced by 1.25 inches for every 1 inch the insulation is buried beyond the 10-inch minimum cover. Ground insulation shall be protected in accordance with Section 4.1.4.

Step 3: Select the Required R-value of Ground Insulation, R_g

Select the minimum R-value, R_g , required for the ground insulating layer from Table A8 based on F_{100} and MAT from Step 1. R_g may be reduced by 0.3 R for every 1-inch thickness that the non-frost-susceptible layer is increased beyond that required in Step 2. R_g may also be reduced by 0.3 R for every 1-inch increase in soil cover thickness, above the 10-inch minimum, over the ground insulation.

Step 4: Select Ground Insulation Type, Calculate Thickness, and Provide Protection

An approved insulation material type shall be selected in accordance with Section A.2.2 of Appendix A. Based on the required R_g value determined in Step 3,

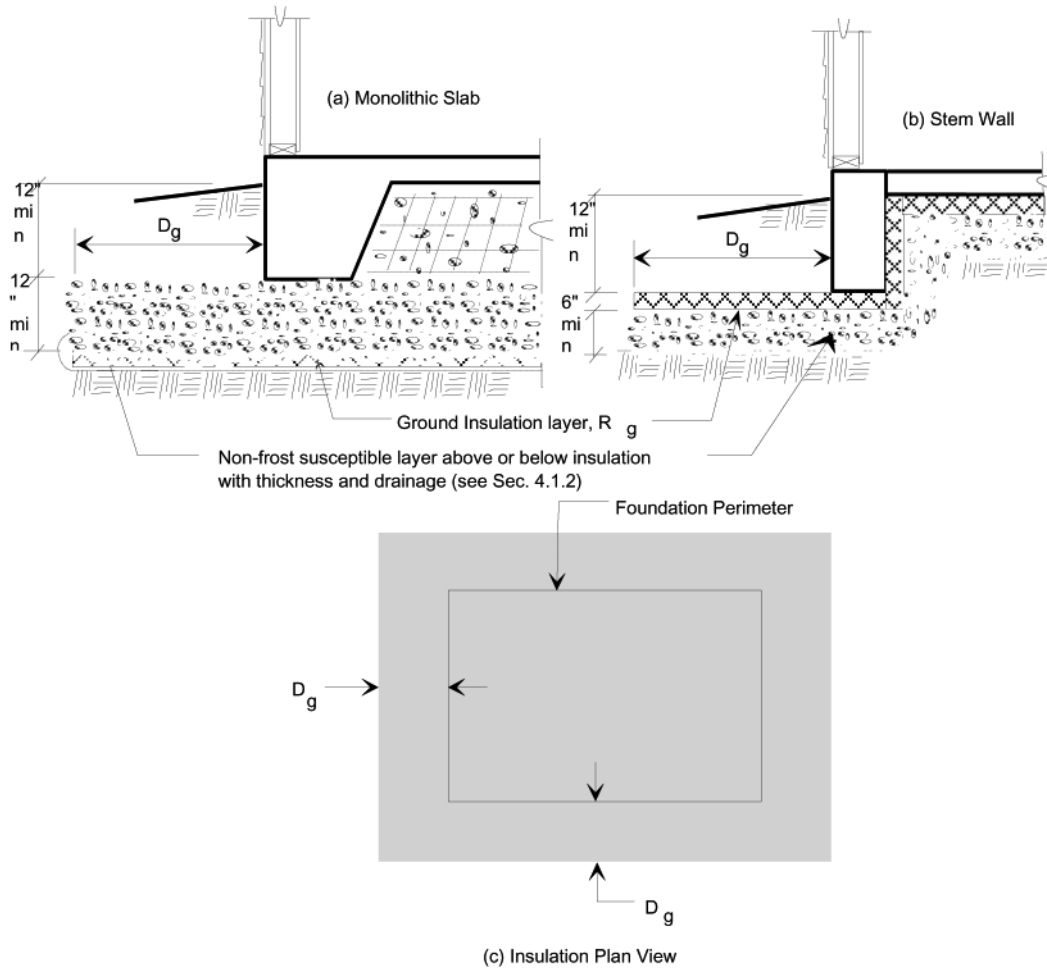


FIGURE 5. Slab-on-Ground Foundation for Unheated Buildings

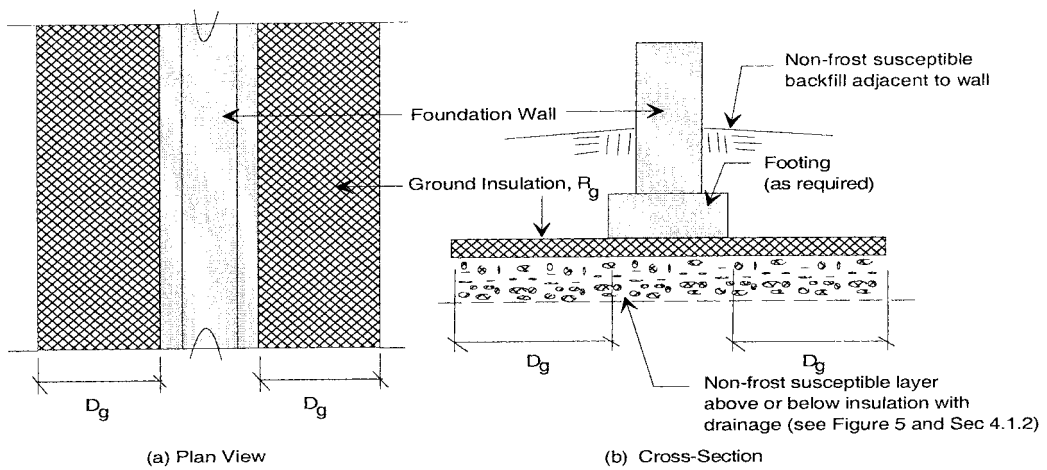


FIGURE 6. Continuous Foundation Wall (Unheated Buildings)

calculate the required thickness of the ground insulation by dividing R_g by the insulation material's effective resistivity, r_{eff} , provided in Table A1 of Appendix A. The insulation material thickness of individual panels shall not be less than the minimum insulation thickness in Table A1 of Appendix A.

Step 5: Check Compressive Load on Ground Insulation

Compressive loads on insulation materials supporting building foundation loads shall not exceed the allowable compressive properties in accordance with Table A1 of Appendix A. Structural loads imposed by the building shall be in accordance with local building code or approved design.

7.2 CONTINUOUS FOUNDATION WALL

For continuous foundation walls exposed to exterior climate conditions on both sides (i.e., vented crawlspaces), follow the design steps in Section 7.1. Insulation shall be selected and installed in accordance with Figure 6 and Table A8 of Appendix A.

Values for D_g and R_g may be adjusted for increased ground cover or thickness of non-frost-susceptible layer, in accordance with Steps 2 and 3 of Section 7.1.

7.3 COLUMN FOUNDATION

For column or pier foundations exposed to exterior climate conditions, follow the design steps in Section 7.1. Insulation shall be selected and installed in ac-

cordance with Figure 7 and Table A8 of Appendix A. Values for D_g and R_g may be adjusted for increased ground cover or thickness of non-frost-susceptible layer, in accordance with Steps 2 and 3 of Section 7.1.

8. SPECIAL DESIGN CONDITIONS FOR FPSF

8.1 SMALL UNHEATED AREAS IN OTHERWISE HEATED BUILDINGS

Where small unheated perimeter areas (as defined in Figure 8) of an otherwise heated building are encountered, follow the design procedure for heated buildings in Section 6, and address each small unheated area as follows:

- Continue the vertical wall insulation of the heated area along the exterior face of the small unheated area in accordance with Figure 9.
- Consider the small unheated area in a corner location and provide frost protection with horizontal wing insulation or increased foundation depth, according to Step 7 of the design procedure for heated buildings (Section 6.1). When required, wing insulation shall be placed at the small unheated area.
- Provide ground insulation as required for unheated buildings under the small unheated area in accordance with Steps 1, 3, and 4 of Section 7.1 and Figure 9.
- Insulation materials supporting structural foundation loads shall be designed in accordance with Step 5 of Section 7.1.

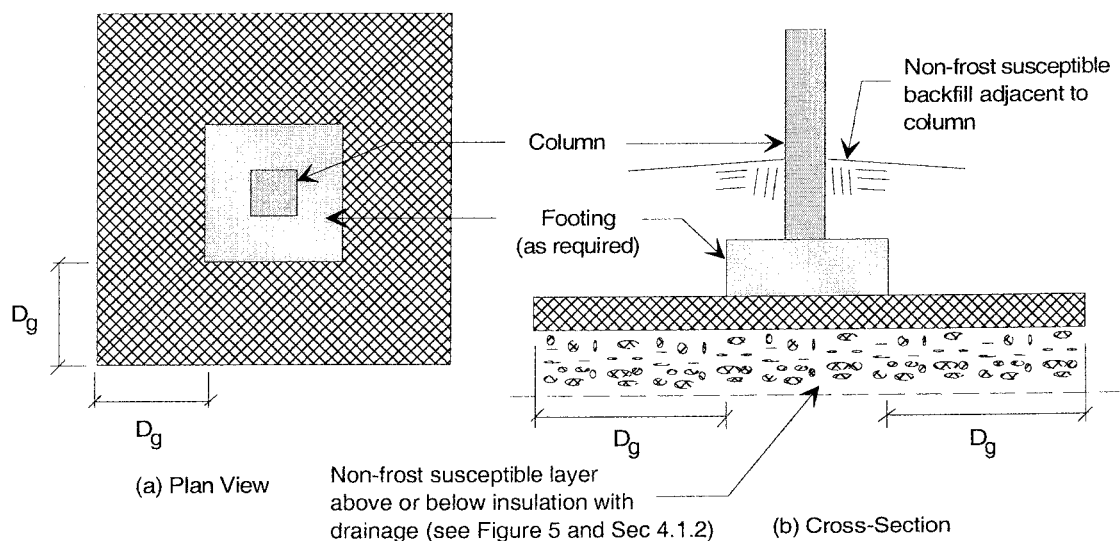


FIGURE 7. Column Foundation (Unheated Building)

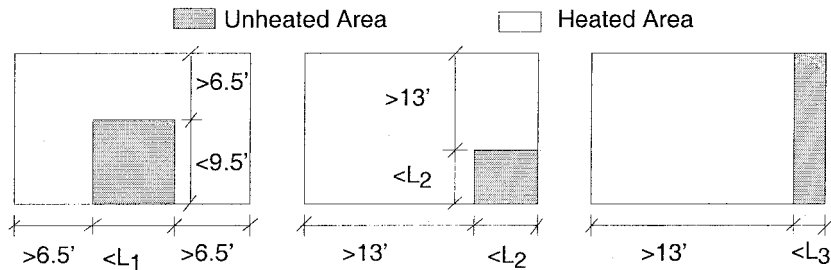
8.2 LARGE UNHEATED AREAS IN HEATED BUILDINGS

When an unheated area is larger than that shown in Figure 8, regard the heated and unheated sections as separate buildings and design the insulation for the large unheated area in accordance with Section 7.1. Insulation shall be installed in accordance with Figure 10

without interruption of the vertical insulation on the heated area of the building.

8.3 SEMI-HEATED BUILDINGS

If the anticipated operating conditions of the building are such that the lowest average monthly internal temperature of a building falls between 41°F



Maximum Size Limit	F_{100} (°F-days)			
	$\leq 2,250$	2,251 to 3,000	3,001 to 3,750	$>3,750$
L_1	13'-0"	11'-6"	10'-0"	6'-6"
L_2	9'-9"	8'-8"	7'-6"	4'-11"
L_3	6'-6"	5'-10"	5'-0"	3'-3"

FIGURE 8. Definition of a Small Unheated Area of a Floor Slab

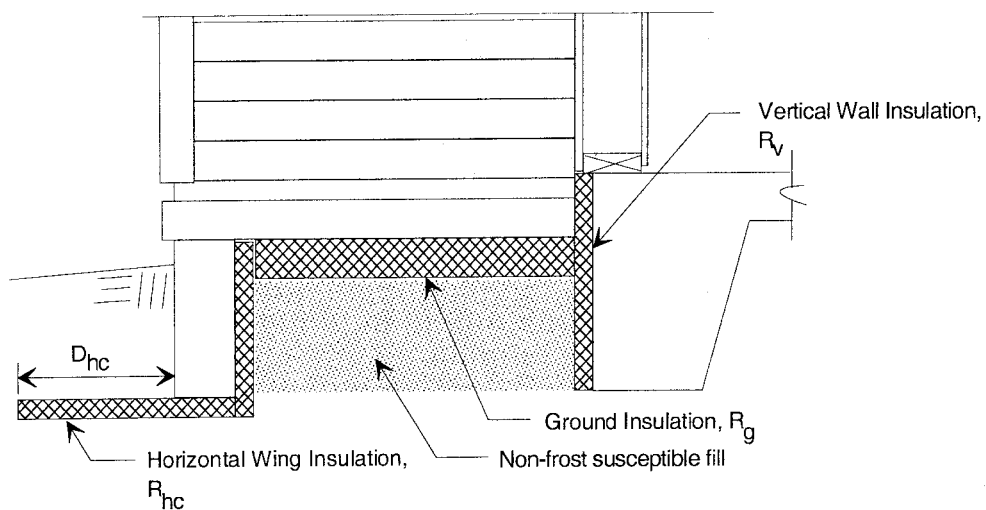
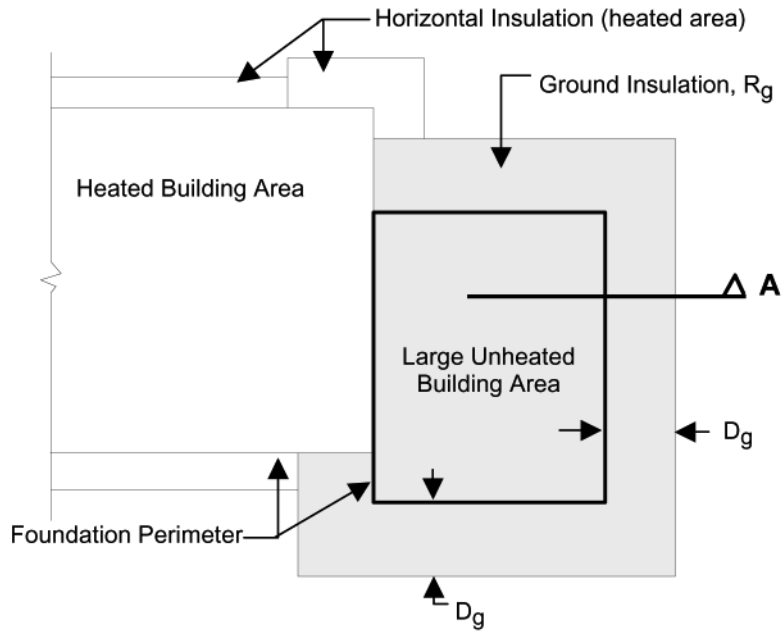
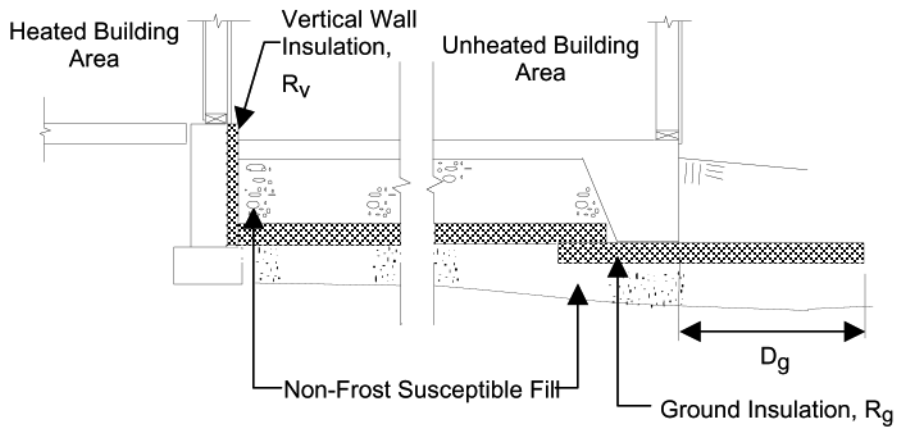


FIGURE 9. Insulation Detail for a Small Unheated Area



Insulation Plan



Cross-Section A

FIGURE 10. Insulation Detail for a Large Unheated Area

(5°C) and 63°F (17°C), the building shall be considered semi-heated (see Table 1). In this case, the foundation shall be designed as a heated building in accordance with Section 6 and the minimum required foundation depth increased by 8 inches (0.2 m) in both wall and corner areas of the semi-heated building.

8.4 COLD-BRIDGES

Cold-bridging shall be prevented unless accounted for in accordance with an approved design. Illustrations for correcting typical cold-bridges are provided in Figure 11.

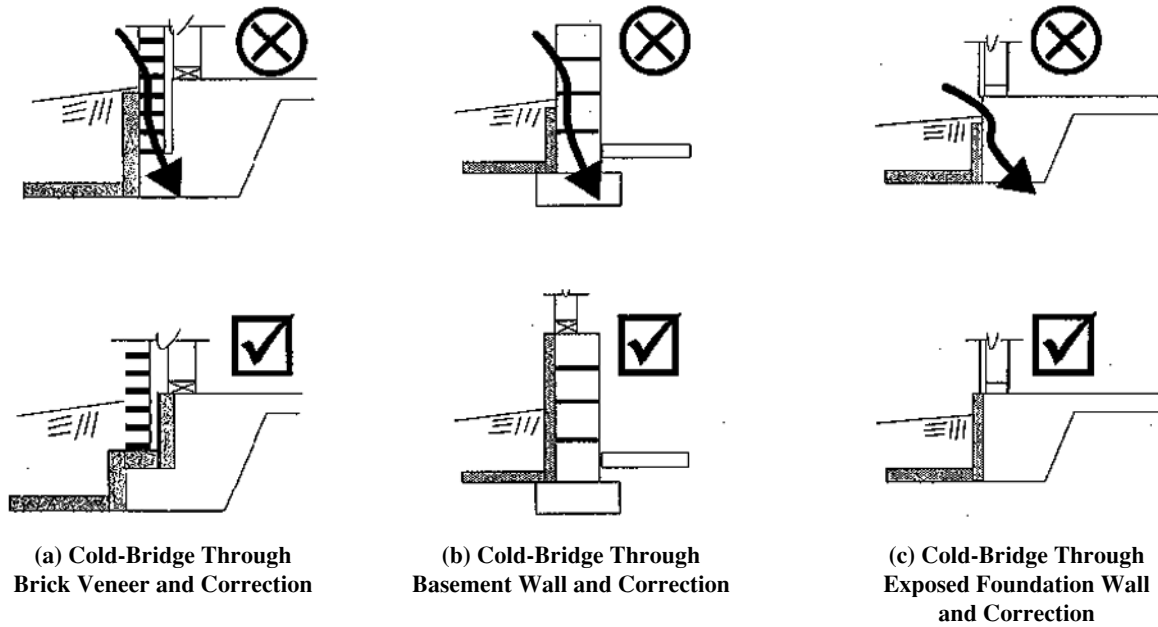


FIGURE 11. Typical Cold-Bridges

APPENDIX A

A. DESIGN DATA

A.1 PURPOSE

This Appendix provides mandatory design data supporting frost-protected shallow foundation (FPSF) design in accordance with this Standard.

A.2 MATERIAL PROPERTIES

A.2.1 Soil Properties

The soil shall be considered to be frost-susceptible unless otherwise classified as non-frost-susceptible in accordance with Section 4.2 of the Standard.

A.2.2 Insulation Materials

The insulation products used to meet the requirements of this Standard shall be expanded polystyrene

or extruded polystyrene manufactured in compliance with ASTM C578, Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation. The effective resistivity, r_{eff} , (R per inch) in Table A1 shall be used to determine insulation thicknesses required for below-ground application. Insulation materials shall be permitted to be placed in multiple layers to meet required insulation thickness, provided the thickness of any individual layer is not less than the minimum thickness required in Table A1.

When these insulation materials are subject to compression from soil and building loads, the insulation shall be supported on suitable bearing material and shall have adequate compressive strength and long-term deformation (creep) characteristics to resist the sustained loads (live and dead) during the expected life of the structure. Compressive (bearing) loads supported by polystyrene insulation shall not exceed the allowable bearing capacities given in Table A1 for each type of insulation.

TABLE A1. Design Values for FPSF Insulation Materials

Insulation Type per ASTM C578	Minimum Insulation Density per ASTM C578 (pcf)	Effective Resistivity, r_{eff} ¹ (R per Inch)		Nominal Resistivity per ASTM C578 (R per inch)	Allowable Bearing Capacity ² (psf)	Minimum Insulation Thickness (inches)	
		Vertical	Horizontal			Vertical	Horizontal
Expanded Polystyrene							
Type II	1.35	3.2	2.6	4.0	N/A	2	3
Type IX	1.8	3.4	2.8	4.2	1,200	1.5	2
Extruded Polystyrene							
Type X	1.35	4.5	4.0	5.0	N/A	1.5	2
Type IV	1.6	4.5	4.0	5.0	1,200	1	1.5
Type VI	1.8	4.5	4.0	5.0	1,920	1	1
Type VII	2.2	4.5	4.0	5.0	2,880	1	1
Type V	3.0	4.5	4.0	5.0	4,800	1	1

¹ Effective resistivity is based on tests from laboratory and field studies of insulation products under long-term exposure to moist, below-ground conditions. 'Vertical' effective resistivity shall be used for insulation placed vertically on exterior foundation walls. 'Horizontal' effective resistivity shall be used for insulation placed horizontally, below ground.

² Allowable bearing capacity is based on ASTM C578 compressive strength at 10% deformation divided by a safety factor of 3.0 for conditions without cyclic loading (i.e., highway vehicle loading).

'N/A' prohibits use where structural foundation loads are supported (i.e., insulation below footings).

A.2.3 Nominal Thermal Properties for Common Building Materials

TABLE A2. Thermal Properties of Some Foundation and Floor Construction Materials (ASHRAE Handbook of Fundamentals, 1997)

Description	Resistivity (hr-ft ² -°F/Btu-in) [R per inch]
Building Materials	
Plywood or wood subfloor	1.25
Particleboard, low density (37 pcf)	1.41
Particleboard, high density (62.5 pcf)	0.85
Particleboard, underlayment (40 pcf)	1.31
Wood (lumber)	0.90
Brick	0.25
8" Concrete masonry unit (cmu), perlite fill	2.10
Cement mortar	0.15
Concrete	0.05
6 mil plastic	Negligible
Finish Flooring Materials	
Carpet and fibrous pad	R = 2.08
Carpet and rubber pad	R = 1.23

A.3 CLIMATE DATA

TABLE A3. Estimates of the Mean Annual Temperature (MAT) and the Design Air-Freezing Index (F_{100}) at Select Locations

Location	Mean Annual Temperature ¹ (°F)	Design AFI Estimates ² 100-Year Mean Return Period, F_{100} (°F-days)
Alaska, Anchorage (Elmendorf AFB)	35.0	3,430
Colorado, Denver	50.3	710
Connecticut, Hartford	49.7	940
Idaho, Idaho Falls	43.8	2,350
Illinois, Chicago	50.6	1,430
Indiana, South Bend	49.4	1,380
Iowa, Fort Dodge	47.4	2,130
Kansas, Topeka	54.1	1,000
Kentucky, Lexington	54.9	720
Maine, Portland	45.0	1,410
Michigan, Lansing	47.2	1,530
Minnesota, Duluth	38.2	3,130
Missouri, Jefferson City	55.1	900
Montana, Lewistown	41.9	2,470
Nebraska, North Platte	48.1	1,690
Nevada, Elko	46.2	1,530
New Hampshire, Concord	45.3	1,600
New York, Syracuse	47.7	1,210
North Dakota, Bismarck	41.3	3,360
Ohio, Mansfield	48.2	1,370
Oregon, Baker	45.6	1,450
Pennsylvania, State College	49.3	1,170
South Dakota, Redfield	43.9	3,010
Utah, Ogden	50.8	1,080
Vermont, Burlington	44.1	2,050
Virginia, Big Meadows	47.2	1,150
Washington, Spokane	47.2	1,230
West Virginia, Elkins	49.4	1,050
Wisconsin, Wausau	42.4	2,490
Wyoming, Sheridan	44.6	2,280

¹ Climatology of the United States No. 81, Supplement No. 3, "Maps of Annual 1961–1990 Normal Temperature, Precipitation, and Degree Days" U.S. Dept of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center, Asheville NC.

² Steurer, Peter M. Methods Used to Create an Estimate of the 100-year Return Period of the Air-Freezing Index. U.S. Dept of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center, Asheville NC (1989).



FIGURE A1. United States Design Air-Freezing Index (°F-Days) Contour Map (an Estimate of the 100-Year Mean Return Period), F_{100}



FIGURE A1, Continued. United States Design Air-Freezing Index (°F-Days) Contour Map (an Estimate of the 100-Year Mean Return Period), F_{100}

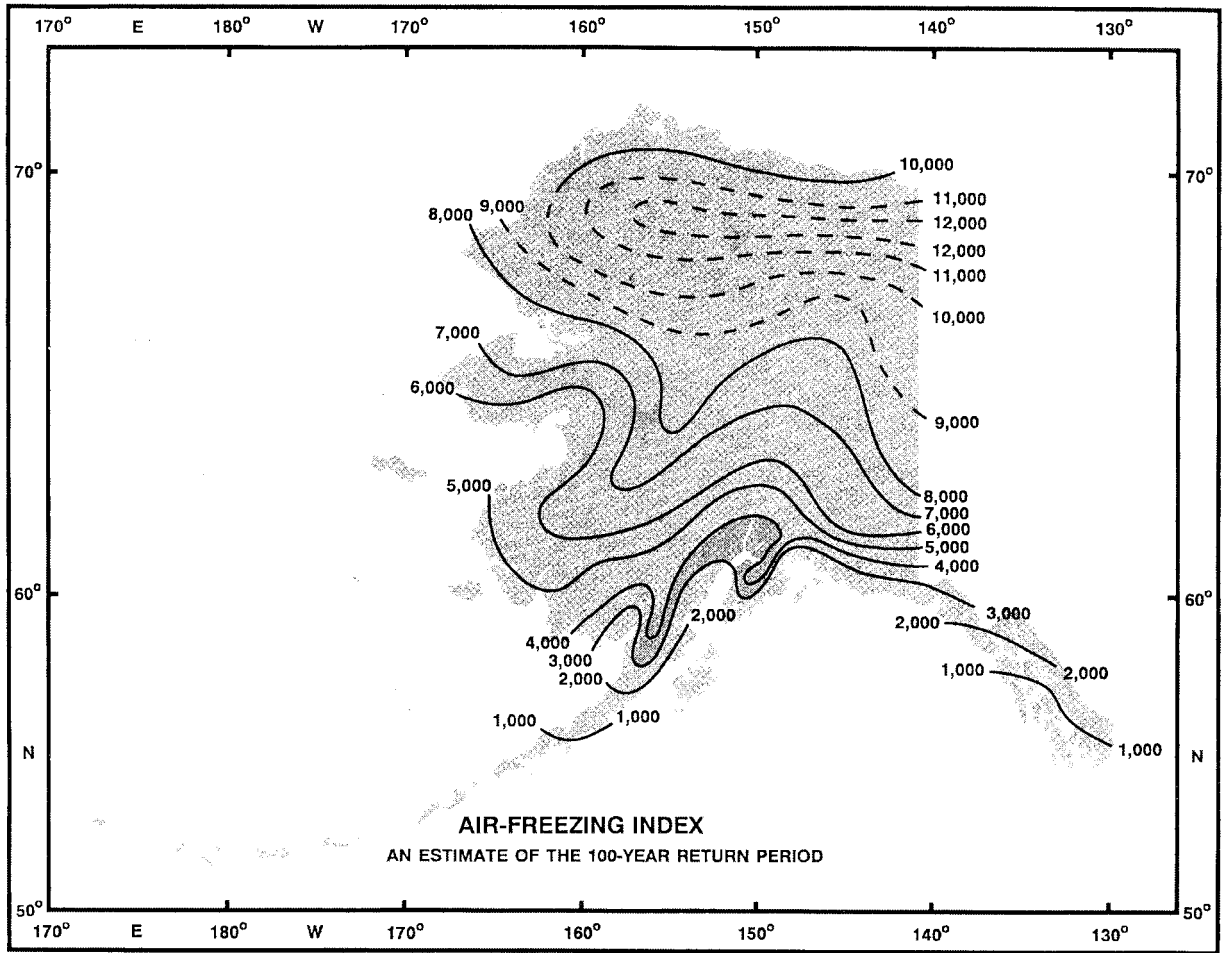


FIGURE A1a. United States Design Air-Freezing Index (°F-Days) Contour Map (an Estimate of the 100-Year Mean Return Period), F_{100}

A.4 FOUNDATION INSULATION DESIGN

TABLE A4. Minimum Thermal Resistance of Vertical Wall Insulation R_v (hr-ft²-°F/Btu)

F_{100} (°F-days)	$R_f \leq 6.0$		$R_f = 15.0$		$R_f = 28.0$	
	$h \leq 12$ in	$h = 24$ in	$h \leq 12$ in	$h = 24$ in	$h \leq 12$ in	$h = 24$ in
375 or fewer	0.0	3.0	4.5	5.7	5.7	8.5
750	3.0	4.6	5.7	5.7	8.5	11.4
1,500	4.5	5.7	5.7	5.7	8.5	11.4
2,250	5.7	5.7	5.7	7.4	8.5	14.2
3,000	5.7	5.7	6.8	8.5	9.7	15.3
3,750	5.7	6.8	8.0	9.7	11.4	17.0
4,500	6.8	8.0	10.2	11.9	13.6	19.3

Interpolation shall be permitted.

TABLE A5. Minimum Foundation Depths Without Wing Insulation or with Wing Insulation at Corners Only

F_{100} (°F-days)	Foundation Depth Along Walls with No Wing Insulation	Foundation Depth at Corners with No Wing Insulation		Foundation Depth at Corners with $R = 5.7$ Wing Insulation at Corners Only		
	h_f (in)	L_c (in)	h_{fc} (in)	L_c (in)	h_{fc} (in)	D_{hc} (in)
1,500 or fewer	12	—	12	—	12	—
2,250	14	—	14	—	14	—
2,625	16	40	24	40	16	20
3,000	20	40	32	40	20	20
3,375	24	60	40	60	24	20
3,750	30	60	51	60	30	24
4,125	36	60	63	60	36	32
4,500	43	80	71	80	43	32

Interpolation shall be permitted.

TABLE A6. Minimum Thermal Resistance of Wing Insulation, R_h , for Use Along Walls with 16-inch (0.4-m) Footing Depth

F_{100} (°F-days)	R-values for Various Wing Widths Along Walls, D_h (inches)						
	12	18	24	30	36	42	48
2,250 or fewer	0.0						
2,625	2.5						
3,000	6.5	6.1	5.3	4.5			
3,375		8.2	7.4	6.5			
3,750			9.1	8.5	7.7		
4,125			11.2	10.2	9.6	8.9	
4,500				12.3	11.4	10.7	10.0

Interpolation shall be permitted.

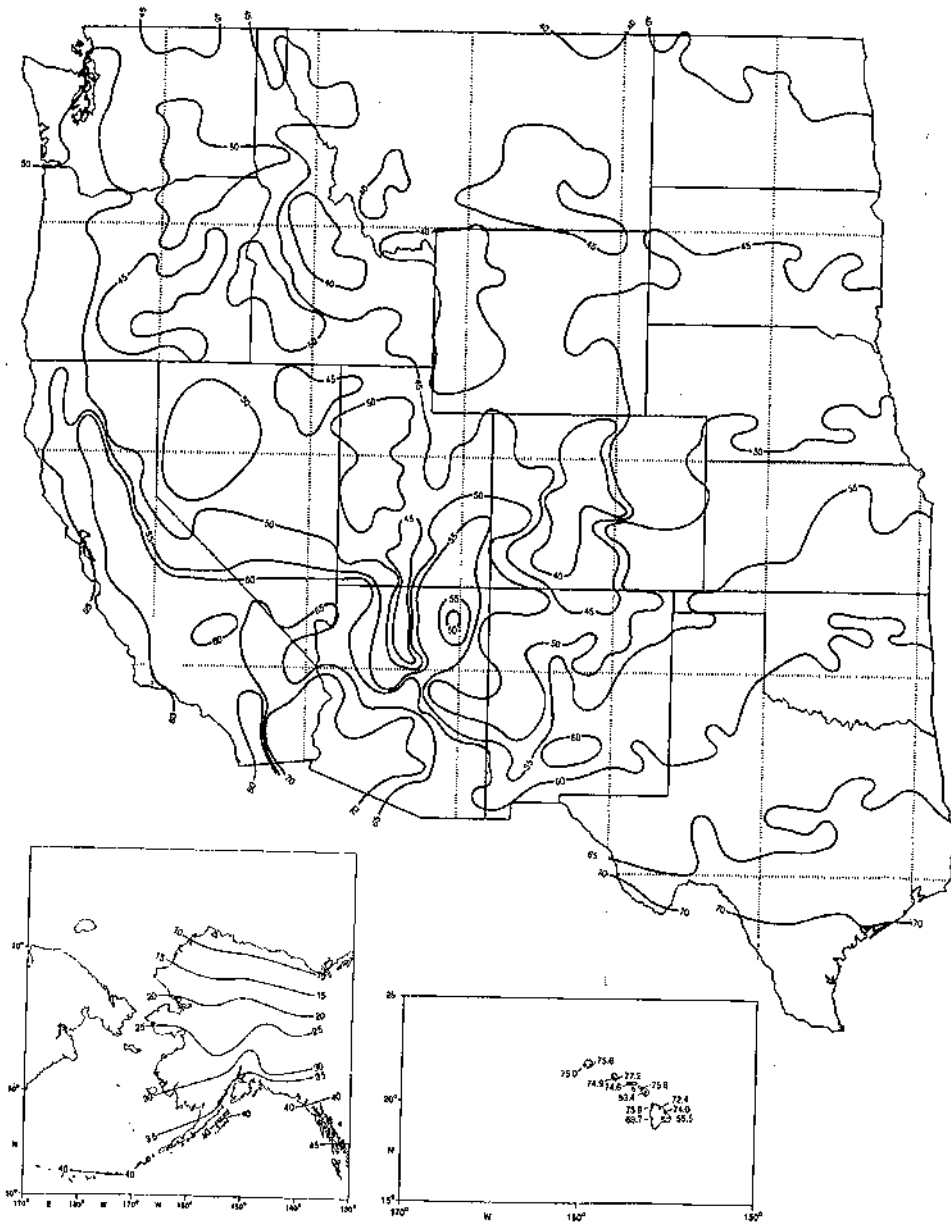


FIGURE A2. Mean Annual Temperature (°F) Contour Map For The United States.



FIGURE A2, Continued. Mean Annual Temperature (°F) Contour Map For The United States.

TABLE A7. Minimum Thermal Resistance of Wing Insulation, R_{hc} , for Use at Corners with 16-inch (0.4-m) Footing Depth

F_{100} (°F-days)	L_c (in)	R-values for Various Wing Widths at Corners, D_{hc} (inches)					
		16	24	30	36	42	48
2,250 or fewer	0	0.0					
2,625	40	6.5	4.9	4.0			
3,000	40	9.6	8.6	8.0	7.4		
3,375	60		11.1	10.5	9.8	9.1	
3,750	60		13.1	12.5	12.0	11.2	10.8
4,125	60			14.5	13.7	13.0	12.5
4,500	80				15.9	15.1	14.8

Interpolation shall be permitted.

TABLE A8. Minimum Thermal Resistance (R-Value) of Ground Insulation, R_g , and Horizontal Extension, D_g , for Unheated Buildings

F_{100} (°F-days)	D_g (inches)	Mean Annual Temperature (°F):				
		≤32	36	38	40	≥41
750 or fewer	30	5.7	5.7	5.7	5.7	5.7
1,500	49	13.1	9.7	8.5	8.0	6.8
2,250	63	19.4	15.9	13.6	11.4	10.2
3,000	79	25.0	21.0	18.2	15.3	14.2
3,750	91	31.2	26.1	22.7	—	—
4,500	108	37.5	31.8	—	—	—

Interpolation shall be permitted.

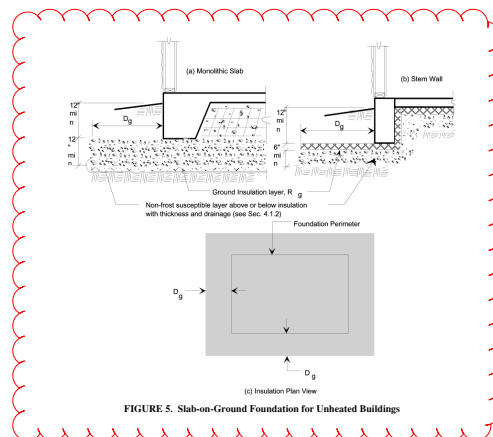


FIGURE 5. Stab-on-Ground Foundation for Unheated Buildings

COMMENTARY

INTRODUCTION

Much of this introduction to the commentary is devoted to some fundamental back ground related to frost penetration, foundation design, and frost-protected shallow foundations (FPSF). The remainder of the commentary gives additional background information, data, references, and explanations in accordance with the content and organization of the Standard.

An FPSF is an alternative to deeper conventional foundations in regions that experience seasonal ground freezing and the potential for frost heave. Figure C1 illustrates an FPSF for a heated building, and a conventional foundation with the footing extending below the design frost depth. An FPSF incorporates strategically placed insulation to effectively raise the frost depth around a building, thereby allowing structurally sound foundations at depths as shallow as 12 to 16 inches (0.4 m) in cold climates with seasonal ground freezing. For a building or portion of a building that is not heated, the insulation strategy involves the use of an insulated foundation pad to conserve geothermal heat and prevent ground freezing. Appropriate use of the above two insulation strategies, dependent upon the thermal conditioning of the interior environment, is critical to the intended performance of an FPSF.

The FPSF technology is applicable to a variety of foundation types including crawlspaces, slabs-on-

ground, and those portions of basements that are at or above grade. Slab-on-ground foundations may be monolithic (thickened edge) or have separate perimeter walls (or grade beams) as in crawlspace construction.

FPSFs may be constructed of concrete, concrete masonry, preservative-treated wood, insulating concrete form systems, and other suitable foundation construction materials and methods. The technology may also be used with isolated spread footings and with combined deep column, pile, or pier foundations with shallow grade beams in between. The primary concern in FPSF design is frost protection. Therefore, the technology may be applied to practically any structurally sound foundation system.

An extensive review of the FPSF technology was conducted prior to the development of this Standard (Morris, 1988; Farouki, 1992). These reviews were followed by several demonstration and monitoring projects sponsored by the US Department of Housing and Urban Development (HUD) to verify the performance of existing European design practices (Crandell, Steurer, and Freeborne, 1994; NAHB Research Center, 1994a). As a result of these efforts, an FPSF Design Guide was developed to serve as a basis for building code acceptance and standardization in the United States (NAHB Research Center, 1994b). The Design Guide was later expanded under sponsorship of the US Department of Energy to include provisions for

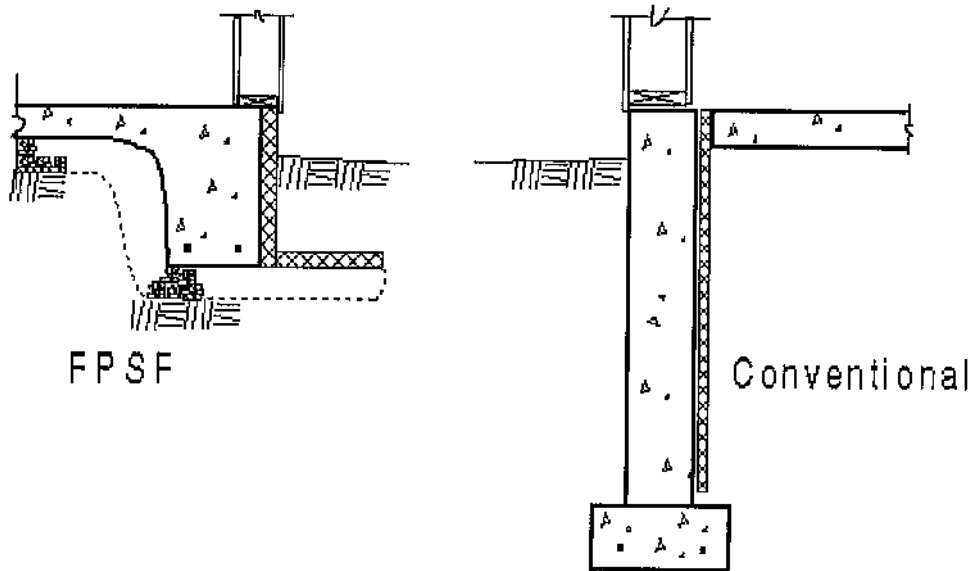


FIGURE C1. Schematic of FPSF and Conventional Foundation Systems